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EFFECT OF RADIATION ON TOPOPAH SPRING TUFF MECHANICAL PROPERTIES

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ABSTRACT

The effect of radiation on the mechanical properties of Topopah Spring tuff was investigated by performing uniaxial compressive tests on irradiated and control samples of the tuff from the potential repository horizon at Yucca Mountain. Test results are presented, including stress-strain curves and peak strength and Young's modulus values. These results show that for homogeneous, uncracked samples of Topopah Spring tuff, exposure to gamma radiation had no discernible effect on the unconfined compressive (peak) strength or the Young's modulus. However, results for samples that contained partially healed subvertical cracks indicate that exposure to radiation may reduce the strength and Young's modulus significantly. This is attributed to weakening of the cementing materials in the cracks and fractures of the samples that were irradiated. These results are preliminary, and additional studies are warranted to evaluate whether radiation weakens cementing materials in welded tuff.

INTRODUCTION

We present results of a suite of uniaxial compressive tests conducted to provide laboratory data to determine how radiation affects the compressive strength of Topopah Spring tuff, which is the host rock type for the proposed geologic repository at Yucca Mountain, NV. Both repository design and performance assessment require information about the effects of radiation on mechanical properties of rock in the near field of a repository. Until now, data describing the effects of radiation on tuff from the potential repository horizon have been unavailable.

We made precise measurements of mechanical properties of rock in uniaxial compression for irradiated and non-irradiated samples of Topopah Spring tuff. Details of the sample preparation, irradiation, and testing equipment and methods can be found elsewhere [1]. To evaluate the effects of radiation, we used a gamma-irradiation method similar to that used in previous investigations of the effects of radiation on Climax granite [2]. For our tests, identical procedures were used for preparing and mechanical testing of all samples, except that some samples were exposed to gamma radiation. Results for the irradiated and non-irradiated samples were then compared. The results are presented in the form of stress-strain curves and tabulated strength and modulus values.

EXPERIMENT

Core samples were machined from a piece of Topopah Spring tuff material that was broken from an outcrop during blasting to excavate a test area at Fran Ridge, Nevada Test Site. Samples for the experiments were prepared as right circular cylinders, 7.6 cm long and 2.5 cm in diameter. In order to have control samples and irradiated samples that could be compared, it was necessary to pair the cores that had similar appearance and that had similar cracks and vugs. All samples were described in detail, including number and location of visible cracks and vugs [1]. We formed 19 pairs from the 39 usable core samples. The sample chamber for the irradiation pool was large enough to hold 15 samples. For each of 15 pairs, we flipped a coin to determine which sample would be irradiated and which would be a control sample. The other nine samples also were included in the study as additional control samples.

One statistical method for analyzing the effect of radiation is known as blocking. A block is a unit of sample material within which the variation of some attribute is less than its variation between blocks. Treatment comparisons are then made within blocks rather than across blocks. The different blocks can be viewed as independent replications of the comparison. The block size in our experiments is two, so the method is also known as the method of matched pairs. For each pair, one sample is exposed to a massive dose of gamma radiation, while the second sample acts as a control. Any radiation effect is detected by comparing the measured parameter between the members of a pair.

Fifteen samples were subjected to a 9.5-MGy (0.9-Grad) dose of gamma irradiation from a ^{60}Co source over a 47-day period, at the LLNL Standards and Calibrations Laboratory. The remaining samples were held as controls. When the radiation exposure was completed, we found that the 15 irradiated cores had developed a distinctive gray color. This finding was not surprising because rock with high quartz content develops color centers when displaced electrons and holes are trapped by impurities and crystal defects. (In most cases, the color change can be reversed by putting the sample under an ultraviolet light source.)

We used a test apparatus equipped with a 50-ton hydraulic loading ram to perform unconfined compression tests on the 39 cylindrical core samples of tuff. Each sample was loaded in uniaxial compression (at a constant strain rate of 10^{-5} s^{-1}) until it failed.

An automatic data acquisition system was used to record the load cell input and output voltages and displacement transducer output voltages, for the uniaxial compressive tests. These data were used to calculate axial stress applied to each sample and the resulting displacements and strains. Stress-strain curves for all 15 pairs of irradiated and control samples were plotted [1].

RESULTS

Typical stress-strain plots are shown in Figures 1 and 2. The solid lines represent the control samples and the heavy dashed lines represent the irradiated samples. Peak strength and Young's modulus values were determined for all the samples in the 15 pairs (Table I).

The irradiated samples had a mean peak strength of 139 ± 73 MPa, whereas the 15 corresponding control samples had a mean peak strength of approximately 154 ± 36 MPa. These values of peak strength are consistent with those reported elsewhere for welded tuff [3]. The large amount of scatter in the values was expected and is generally attributed to the heterogeneity in the form of cracks and vugs present in the rock. Average Young's modulus values found for the 15 irradiated and 15 control samples were 23 ± 5 GPa and 25 ± 3 GPa, respectively.

Stress-strain curves show that most of the samples behaved in a linear elastic manner up to the point of brittle failure, and that the Young's modulus for matched cores was similar (e.g., Figure 1, top). Stress-strain curves for some samples show nonlinear behavior at stress levels below the peak stress (e.g., Figure 1, bottom). For many of the pairs, the behavior for each of the samples was quite similar, but for some of the pairs, dissimilar behavior was observed for the two samples (e.g., Figure 2). To further evaluate this behavior, we divided the 15 pairs into two groups, termed the homogeneous and heterogeneous groups, based on stress-strain behavior for the pair. The heterogeneous group contained the pairs having one sample that failed at a very low stress level (e.g., below 50 MPa) compared to the other sample (typically above 100 MPa). Nearly all of the samples in the homogeneous group exhibited catastrophic brittle failure (e.g., Figure 1). Both irradiated and non-irradiated samples in this group had a higher mean peak strength than that determined for the total dataset, i.e. 185 ± 49 MPa for the irradiated and 169 ± 24 MPa for the control samples. Values for Young's modulus for the irradiated and non-irradiated samples in the homogeneous group were identical with similar standard deviations, i.e. 26 ± 2 GPa. For the homogeneous samples of welded tuff, radiation has little effect on the mechanical behavior in compression.

For the heterogeneous pairs, we found a significant difference between the mean peak strength observed for the irradiated and non-irradiated samples (e.g., Figure 2). The irradiated samples had a mean strength of approximately 70 ± 38 MPa, and the non-irradiated had a mean strength of approximately 131 ± 37 MPa. Among the heterogeneous pairs, the average value of Young's modulus for the irradiated samples, 19 ± 6 GPa, was also significantly lower than that for the non-irradiated samples, 23 ± 3 GPa. Preliminary examination of the core descriptions [1] for these samples indicated that, for many of the pairs in the heterogeneous group, both samples in the pair contained preexisting vertical or subvertical cracks. Also, for the irradiated samples, the failure occurred along one of these preexisting cracks. For the non-irradiated samples in this group, failure occurred more frequently by catastrophic or explosive fracture. A possible explanation of these results is that exposure to radiation weakened the cementing material in the pre-existing fractures. This tuff commonly contains carbonate cementing materials, but these samples were not analyzed chemically to determine the composition of the cementing materials. It is possible that the fracture orientation and characteristics of the samples in each pair are not identical. However, our preliminary results show that irradiated samples with pre-existing fractures were weakened by the irradiation, when compared to the control samples.

CONCLUSIONS

Our preliminary results (summarized in Table II) indicate that for intact samples of Topopah Spring tuff, exposure to gamma radiation had no discernible effect on the unconfined compressive (peak) strength or the Young's modulus. However, results for samples that contained partially healed, preexisting vertical or subvertical cracks (the heterogeneous group) indicate that radiation may cause significant degradation of the strength and Young's modulus (see Table II).

One possible mechanism that could weaken a carbonate cementing material in a high radiation field is degradation of the carbonate by nitric acid formed by irradiation of moist air. This hypothesis could be evaluated by performing another similar set of experiments and changing the experimental procedure so that the irradiation vessel would be flooded with an inert gas such as argon instead of using air. A second possible mechanism is alteration of some of the hydrated minerals in the cementing material through radiolysis of the waters of crystallization. The alteration would weaken the cementing material and thus degrade the compressive strength.

Additional studies are warranted to evaluate whether radiation does weaken cementing materials in welded tuff. However, if this is a real phenomenon, it has significant implications for the behavior of rock in the near-field region of the proposed nuclear waste repository, and should be taken into account when the shielding for the waste packages is designed. If shielding were to be inadequate, the radiation field would be expected to affect only rock exposed on the surface of excavated drifts and to penetrate only a few centimeters into the rock. However, the rock in this region would also experience the highest temperatures and stresses in a repository, and possibly high humidity. Weakening of fracture-filling materials may cause unanticipated spalling, which may change the amount and nature of rock fragments that would come in contact with the waste containers. In addition, changes in fracture properties, such as fracture shear strength, compressibility, and permeability could also occur. Changes in these properties would affect the thermomechanical and thermohydrological behavior of the rock in the near-field region. In particular, changes in the shear strength of cementing material in fractures would enhance stress gradients that would occur within the rock mass and may affect rock mass behavior in unanticipated ways, including movement of rock blocks along fractures.

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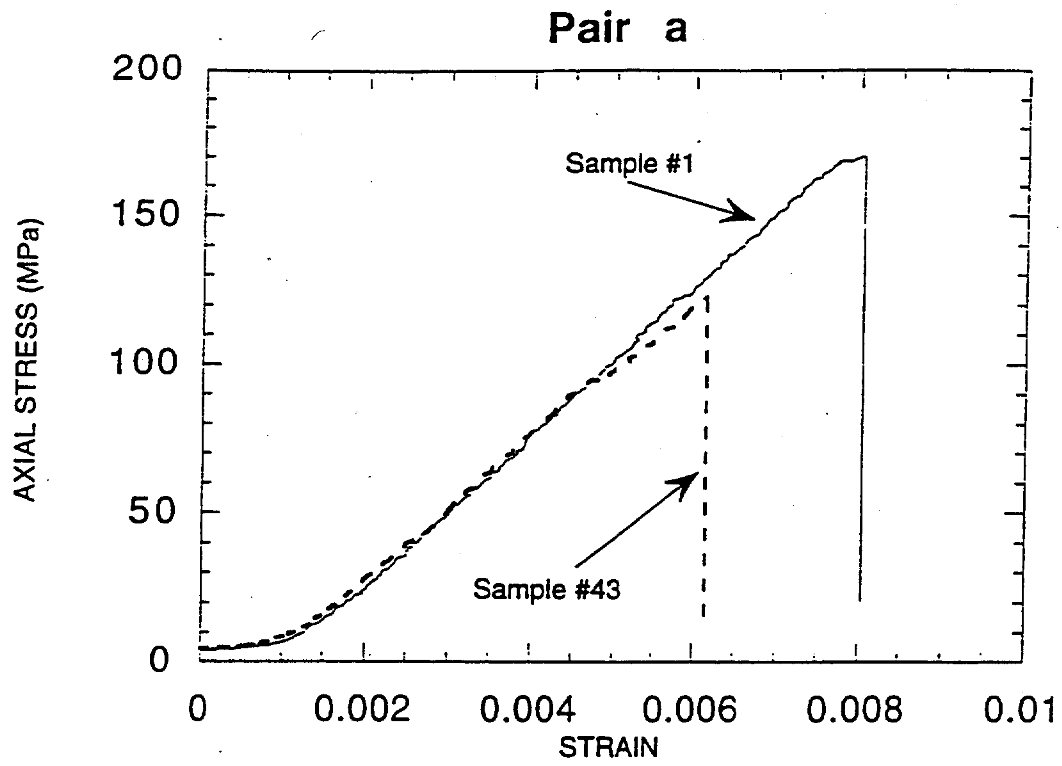
Table I. Results from the uniaxial tests on each sample in pairs a–o.

Pair	Sample ID No.	Peak strength (MPa)	Young's modulus (GPa)	Rad. (Y/N)	Comments
a	1	170.5	25.4	N	Chipping at 122, 158, and 166 MPa.
	43	123.0	23.3	Y	Vertical crack formed through a preexisting vug near 100 MPa.
b	4	135.6	24.6	N	A sliver cracked off at about 87 MPa.
	8	221.2	27.1	Y	No chipping or cracking before failure.
c	7	191.1	27.8	N	No cracking or chipping before failure.
	28	213.4	25.9	Y	No cracking or chipping before failure.
d	9	58.9	17.9	N	Failure along preexisting fracture.
	10	150.5	21.2	Y	Preexisting crack opened at about 122 MPa.
e	11	192.6	27.5	N	Ram pressure increased somewhat slower than in other tests.
	16	151.9	26.1	Y	No cracking or chipping before failure.
f	12	164.5	25.0	N	No cracking or chipping before failure.
	37	63.0	23.9	Y	See comments in [1].
g	14	201.6	26.7	N	Chipping at about 193 MPa.
	22	236.0	26.4	Y	No cracking or chipping before failure.
h	20	158.3	27.1	N	Cracking and chipping around 148 MPa.
	6	204.0	26.8	Y	A chip fell off at 160 MPa.
i	25	149.0	25.4	N	Chipping at about 131 MPa.
	2	47.9	6.8	Y	Failure along preexisting fracture.
j	26	128.4	24.2	N	Chipping at about 122 MPa.
	40	76.3	19.0	Y	Chipping along a preexisting crack.
k	30	132.4	23.1	N	Large chips fell off; the test was paused and restarted.
	3	96.0	23.3	Y	Chipping at about 87 MPa.
l	31	116.8	22.7	N	Some cracking.
	39	31.9	21.0	Y	Failure along a large preexisting fracture.
m	33	168.3	23.2	N	No chipping or cracking before failure.
	32	213.0	26.6	Y	Cracking and chipping at about 193 MPa.
n	41	166.6	25.2	N	Chipping at about 140 MPa.
	35	51.3	22.5	Y	Failure due to preexisting crack.
o	44	174.1	27.7	N	No cracking or chipping before failure.
	15	205.8	27.3	Y	Chipping at about 193 MPa.



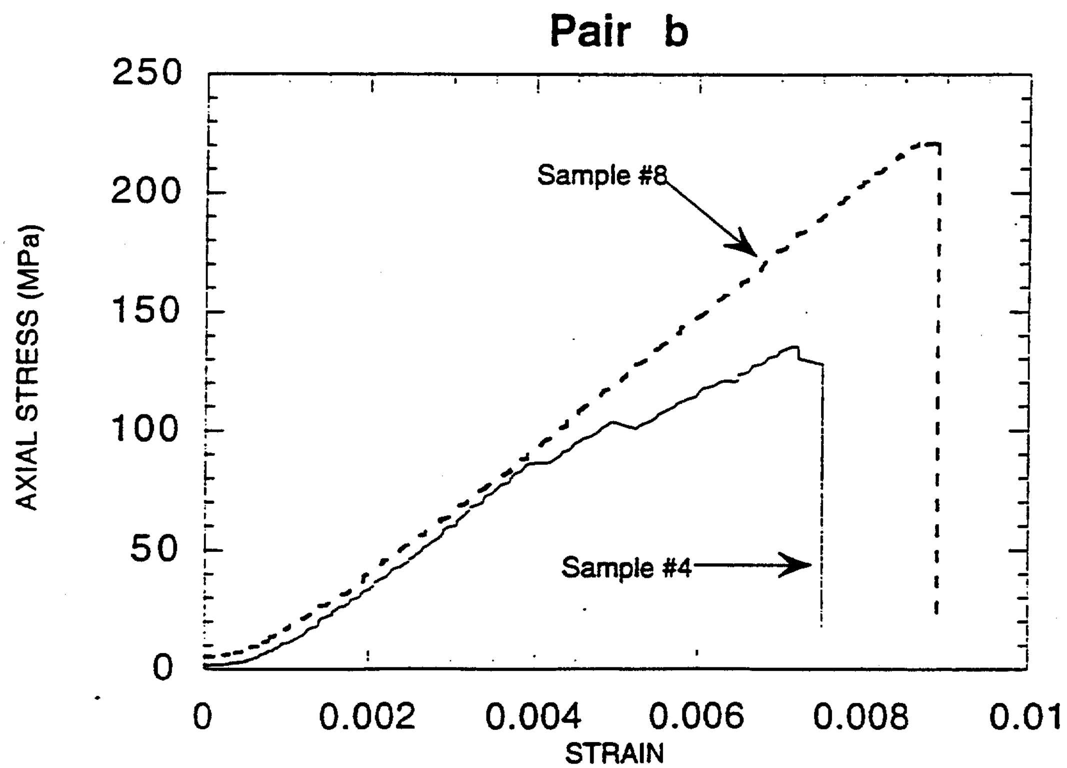
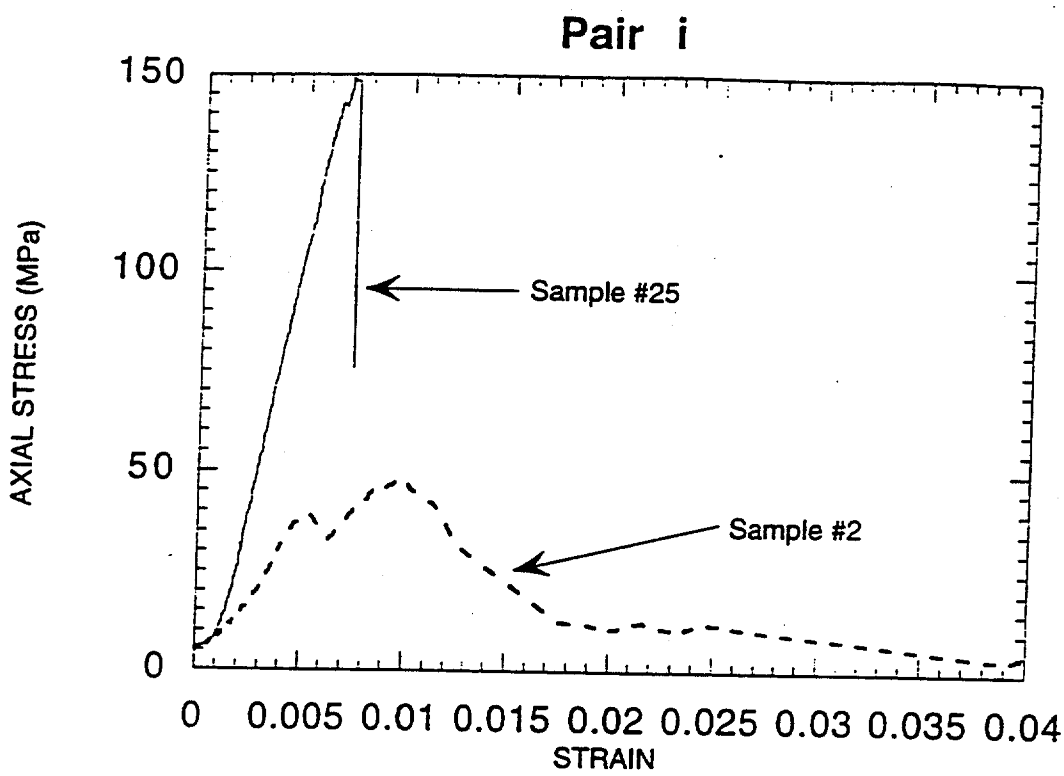


Figure 1. Stress-strain curves for four typical cores. In pair a (top), sample #43 was irradiated and sample #1 was the control. In pair b (bottom), sample #8 was irradiated and #4 was the control. Note nonlinear behavior for sample #4.



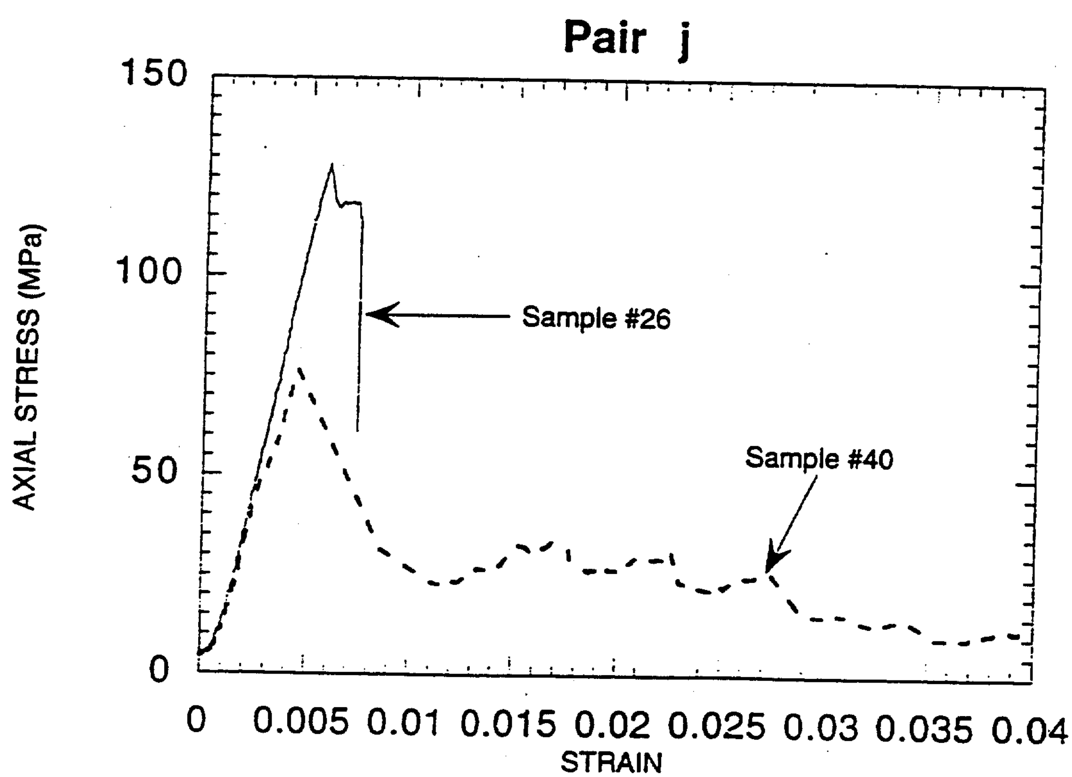


Figure 2. Stress-strain curves for some heterogeneous cores. In pair i (top), sample #2 was irradiated and #25 was the control. For pair j (bottom), sample #40 was irradiated and #26 was the control. The irradiated samples failed along preexisting cracks, at much lower stresses than the peak stresses for the control samples.

Table II. Average values for peak strength and Young's modulus for various groups of samples.

Samples	Rad. (Y/N)	Average peak strength (MPa)	Standard deviation	Average Young's modulus (GPa)	Standard deviation
Pairs a–o	Y	139.0	73.4	23.1	5.2
(15 pairs)	N	153.9	36.1	24.9	2.6
Homogeneous samples	Y	184.9	48.9	25.9	1.5
(9 pairs)	N	169.4	24.3	25.9	1.9
Heterogeneous samples	Y	70.2	38.4	19.1	5.7
(6 pairs)	N	130.7	36.8	23.4	2.6

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REFERENCES

1. S.C. Blair, J. M. Kelly, O. Pine, R. Pletcher, and P. A. Berge, *Effect of Radiation on the Mechanical Properties of Topopah Spring Tuff,* LLNL report UCRL-ID-122899 (Lawrence Livermore National Laboratory, Livermore, CA, 1996), 29 pp.

2. W.B. Durham, J. M. Beiriger, M. Axelrod, and S. Trettenero, *The effect of gamma irradiation on the strength and elasticity of Climax Stock and Westerly granites,* Nuclear and Chemical Waste Management **6**, 159–168 (1986).

3. R. H. Price, K. G. Nimick, and J. A. Zirzow, *Uniaxial and Triaxial Compression Test Series on Topopah Spring Tuff,* SNL report SAND82-1723 (Sandia National Laboratory, Albuquerque, NM, 1982).